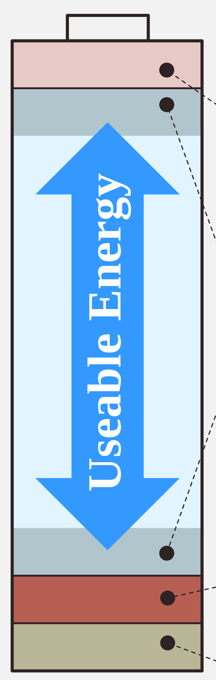
Robust cell-level control of large battery packs

Approach and Vision

- Achieve cost-effective dynamic cell-level control and diagnostics
- Drive cells to non-conservative physical limits and homogeneous end-of-life
- Improve energy/power utilization, lifetime, reliability, safety

Today's Battery System



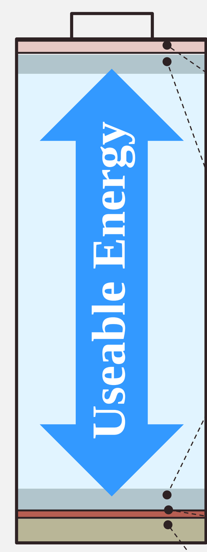
Passive cell balancing slow, wastes energy

Cell rate-capability voltage-limited with conservative safety margins

Energy limited by lowest performing cell in pack. Cell inhomogeneity *worsens* with age

Uncertain battery state

Proposed Battery System



Efficient, fast differential cell-power processing

Electrochemical MPC reduces conservative limits and extends low temperature cell rate-capability

All energy of disparate cells is available. Cell inhomogeneity *decreases* with age

Improved knowledge of battery electrochemical state

Cost-Benefit Analysis and Life-Prognostic Modeling

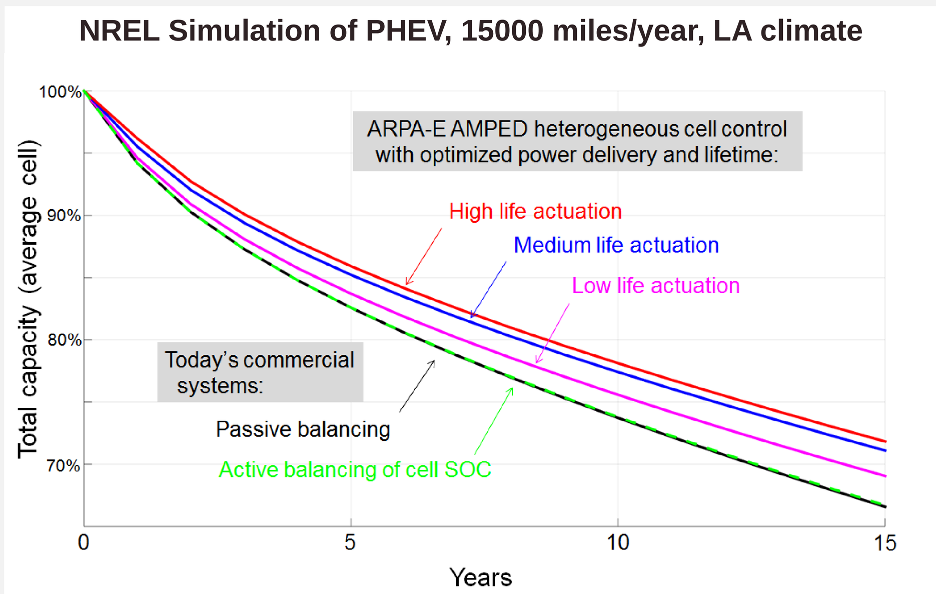
Problem: Packs with well-matched cells may grow to 10% capacity imbalance over 10 years (model prediction)

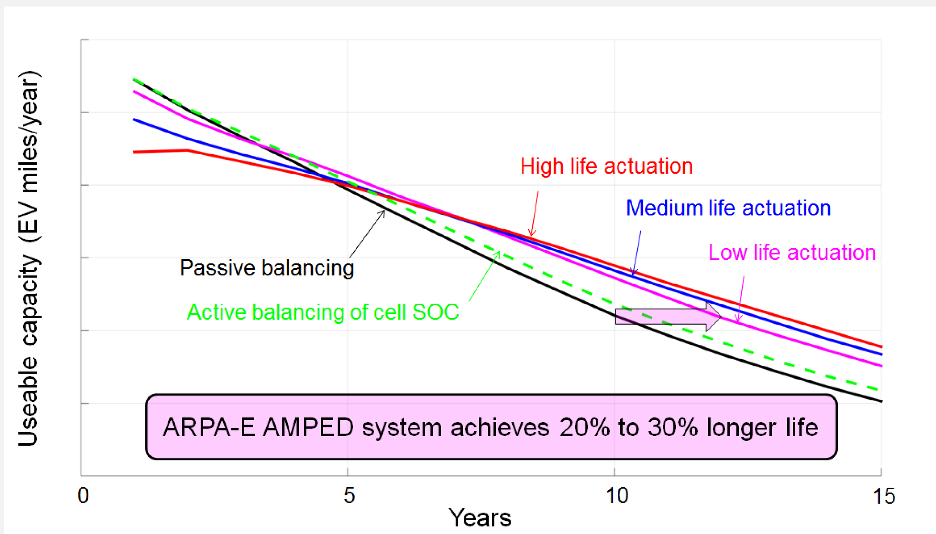
Solution: Cost neutral active balancing system. Displaces HV-12V DC-DC

- Benefit – Utilization: Active balancing allows full utilization of cell energy
- Benefit – Lifetime: Removing limitation of weakest cell can extend life
  - 20% for PHEV
  - 40%-80%* for BEV75 (*passively cooled pack)
  - 35% for grid applications and automotive 2nd use
- Benefit – Pack thermal design: Eliminates the need for expensive thermal management that tightly controls cell-to-cell temperature differences
- Benefit – Performance: Heterogeneous cell control and electrochemical MPC co-optimize power delivery and lifetime

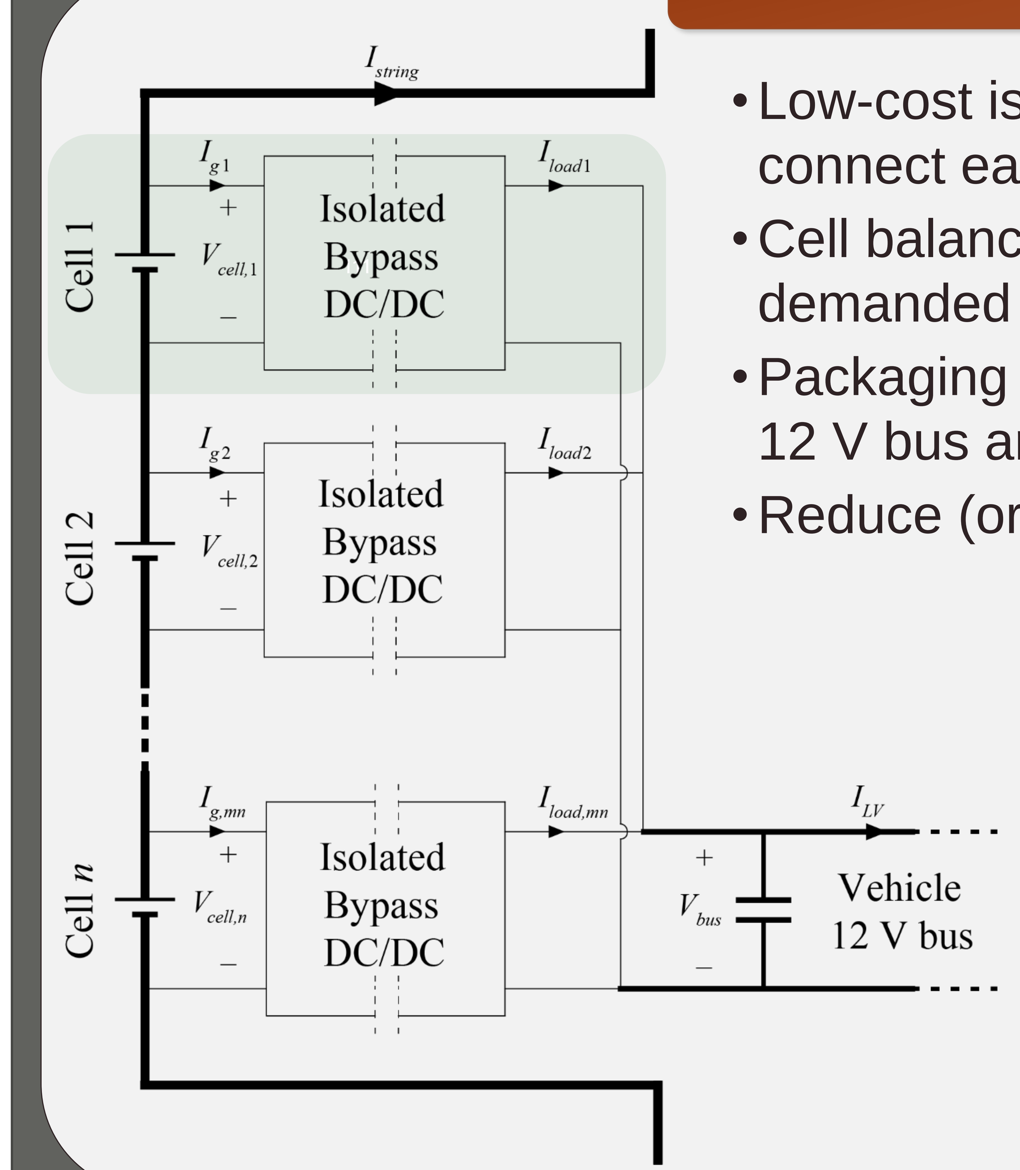
Validation: 12 month pack aging test with A/B comparison of passive/active balancing hardware employing heterogeneous cell control

NREL Simulation of PHEV, 15000 miles/year, LA climate

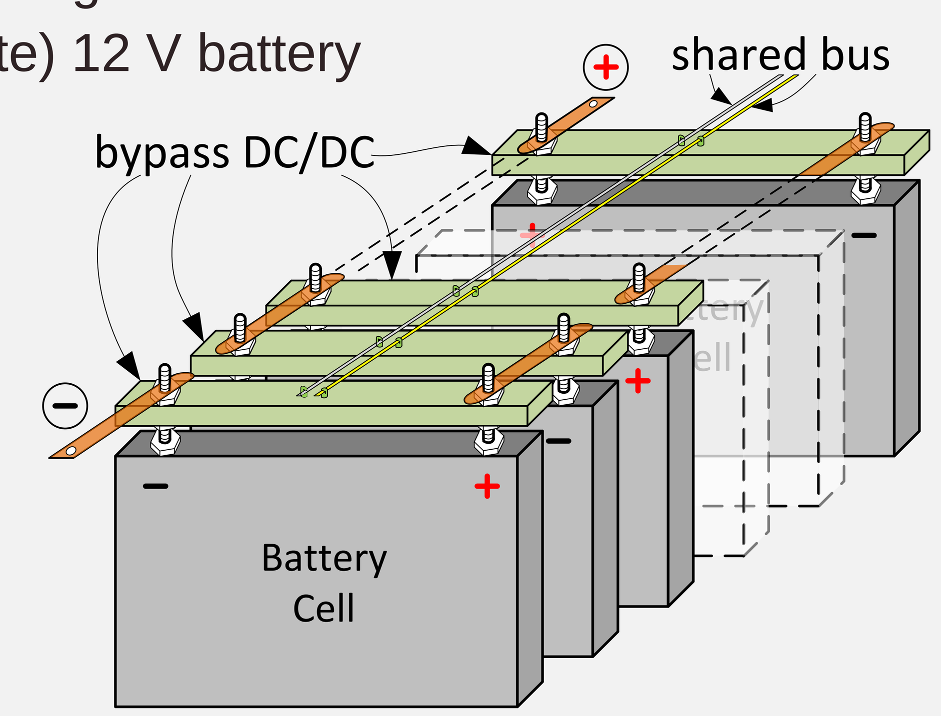




System Architecture

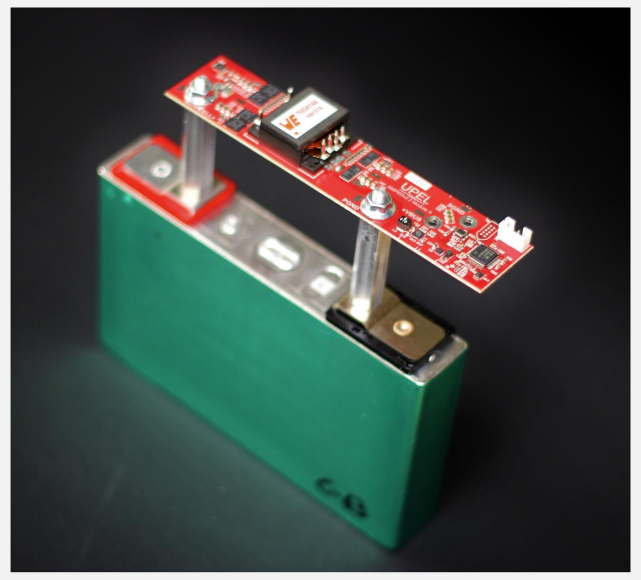


- Low-cost isolated bypass DC/DC converter modules connect each cell to the vehicle 12 V bus
- Cell balancing is achieved by differentially supplying current demanded by the 12 V bus
- Packaging and wiring is simplified with parallel connection to 12 V bus and single digital communication line for all data
- Reduce (or eliminate) 12 V battery



Battery Cell	
Capacity	25 Ah
Series Resistance	~ 1 mΩ

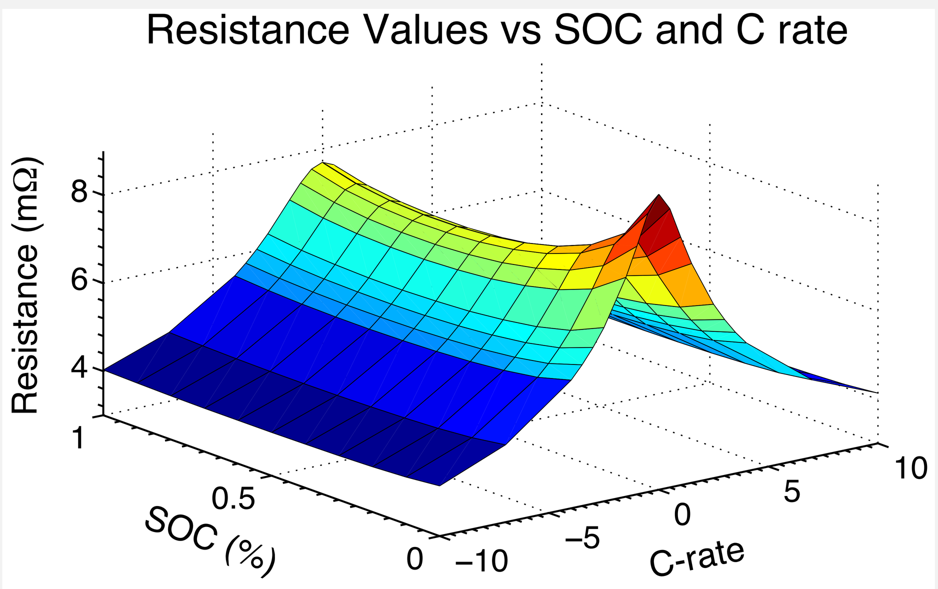
Bypass Converter	
Power Rating	30 W
Peak Efficiency	93 %



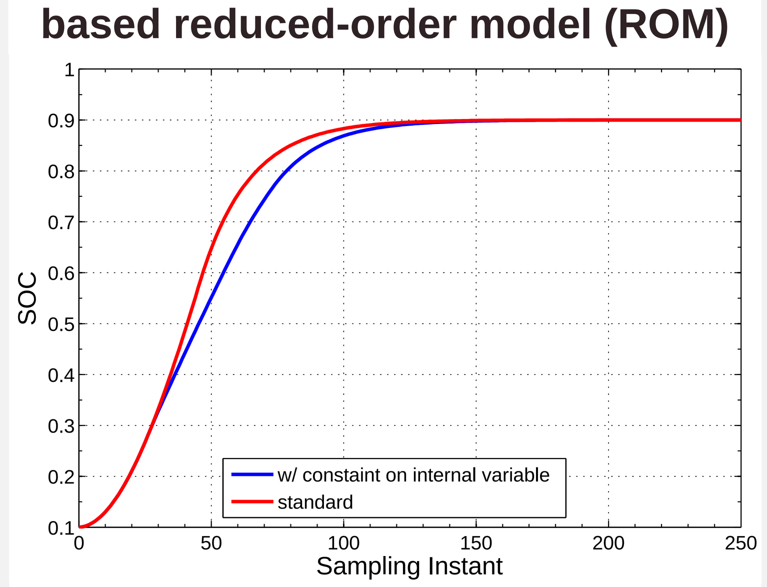
Electrochemical Model-Predictive Control

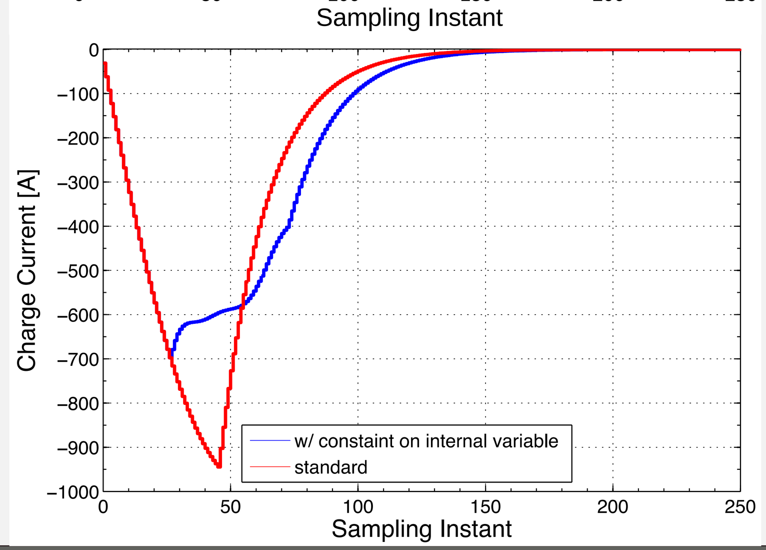
- Improve lithium ion battery performance with model predictive control(MPC) using physics-based electrochemical models to achieve battery performance closer to theoretical limits
- Generate simple yet highly accurate reduced-order cell models amenable to fast computation
- Identify internal physical and electrochemical parameters via experimentation to populate models

Resistance Values vs SOC and C rate



Fast charge with MPC and physics based reduced-order model (ROM)





Team Partners

Utah State University

NREL National Renewable Energy Laboratory

University of Colorado Boulder

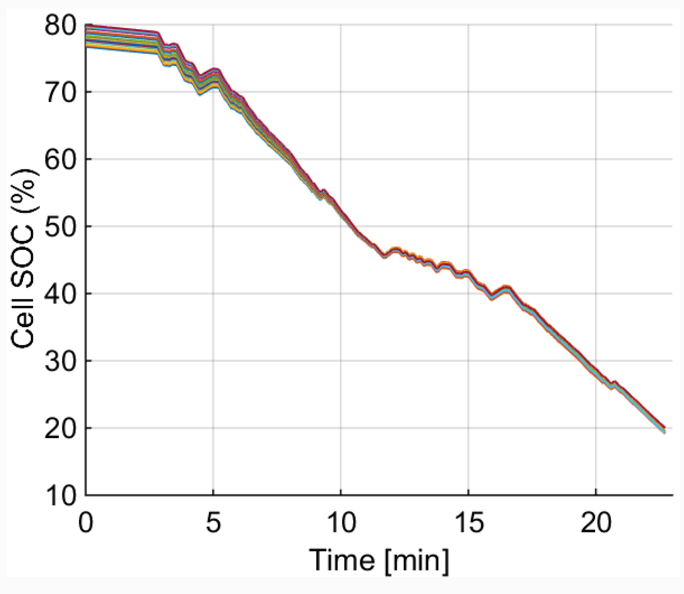
UCCS University of Colorado Colorado Springs

Ford

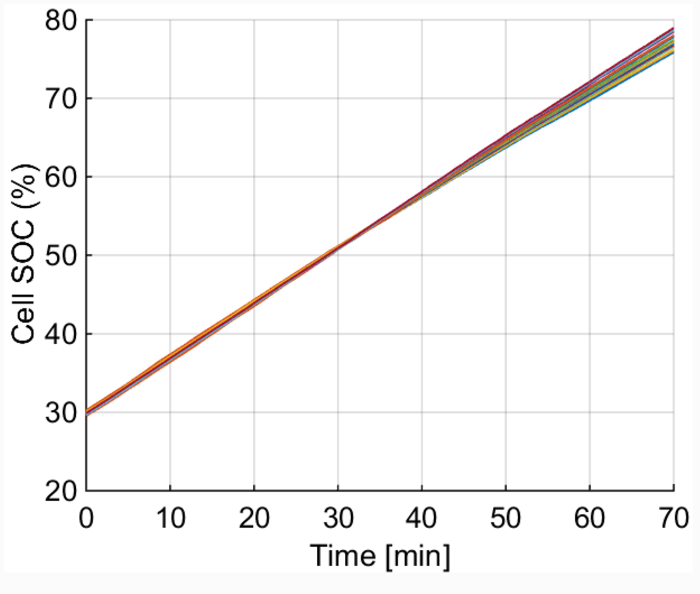
Experimental Validation and Program Status

Battery Pack Integration with Bypass Converters

Pack level results with heterogeneous cell control



Discharge Cycle (US06 drive cycles)



Charge Cycle (15 A Constant Current)

Completed (Years 1 – 2)

- Hardware development and pack level integration
- Heterogeneous cell control algorithm development and integration with hardware
- Initial electrochemical model parameter identification and MPC simulation

Year 3 Plan

- Launch new Partner Program to provide industry feedback
- Validate heterogeneous cell control through long term pack aging
- Further develop electrochemical MPC and perform cell-level hardware validation
- Develop cost-constrained control algorithms and hardware
- Demonstrate combined heterogeneous cell control and MPC at the pack level